

(19)

Europäisches Patentamt

European Patent Office

Office européen des brevets



(11)

EP 0 971 485 A1

(12)

EUROPEAN PATENT APPLICATION

(43) Date of publication:
12.01.2000 Bulletin 2000/02

(51) Int Cl.7: H04B 1/707

(21) Application number: 98112673.3

(22) Date of filing: 08.07.1998

(84) Designated Contracting States:
AT BE CH CY DE DK ES FI FR GB GR IE IT LI LU
MC NL PT SE
Designated Extension States:
AL LT LV MK RO SI

(71) Applicant: SIEMENS AKTIENGESELLSCHAFT
80333 München (DE)

(72) Inventors:
• Götsche, Jürgen, Prof. Dr.-Ing.
44229 Dortmund (DE)
• Haardt, Martin, Dr.-Ing.
81477 München (DE)
• Vollmer, Marius
44339 Dortmund (DE)

(54) Multiuser detection in CDMA using a correlation matrix

(57) A radio communications receiver which operates to detect radio signals and to recover data representative of the radio signals in the presence of contemporaneously detected interfering signals, the radio communications receiver comprising means to detect the radio signals (6, 8) and to generate digital base band signals representative of the radio signals, means to form a correlation matrix (12) from the base band signals, a data processor (16) which operates to generate a factor

(R) of the correlation matrix (S), and to recover the data from the factor, wherein the data processor (16) operates to generate the factor (R) by calculating first elements of the factor (R) from the correlation matrix (S) using a factorisation algorithm, in accordance with a pre-determined structure of the factor (R), and forming second elements of the matrix (R) by selectively copying first elements in accordance with the pre-determined structure.

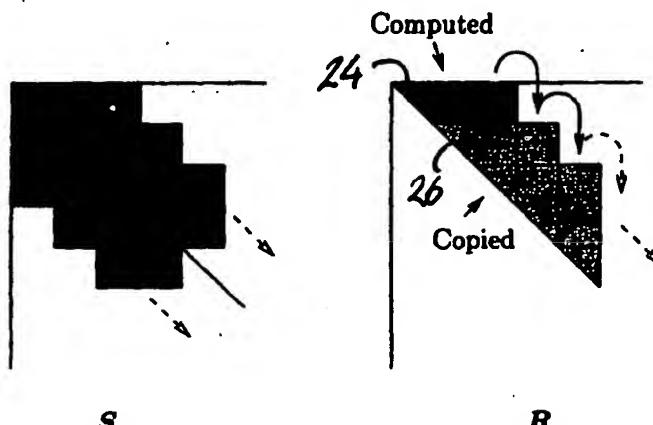


Figure 4

EP 0 971 485 A1

Description

[0001] The present invention relates to radio communications receivers and in particular to radio communications receivers which operate to detect radio signals and to recover data representative of the radio signals in the presence of interfering signals. The present invention also relates to methods of receiving radio signals and recovering data representative of the radio signals in the presence of interfering signals.

5 [0002] In data and signal processing applications, there is often a requirement to factorise a matrix of signal samples to the effect of providing a factor matrix having particular characteristics. For example, the desired matrix factor may be upper triangular or lower triangular in that the lower or upper part of the matrix may be filled with zeros. As a result, 10 the factorised matrix may be interpreted as a set of simultaneous equations and these equations solved in a manner facilitated by the upper or lower triangular form.

15 [0003] An example where such matrix factorisation is required is in radio communications receivers, and in particular radio communications receivers which are arranged to detect radio signals and generate data from these radio signals in the presence of contemporaneously detected interfering signals. Such is the case with radio systems arranged to operate with code division multiple access. Code division multiple access is a radio communications technique in which data to be communicated is combined with a spreading code in some way before being modulated onto a radio frequency carrier signal. At the receiver the radio signals are detected and the data is recovered by de-spreading the radio signals with knowledge of the spreading code used at the transmitter to form the radio signals. As a result of the spreading of the data, the receiver is able to generate a gain in the power of the detected signal with respect to noise 20 and other signals for the wanted signal. As such, signals from a plurality of transmitters may be contemporaneously transmitted using different spreading codes and separated at corresponding receivers to the effect that the data which the radio signals represent may be recovered in spite of the presence of the interfering signals from the other transmitters. However in order to detect the data from a wanted radio signal, the receiver is required to reject the unwanted signals which are contemporaneously detected with the wanted signal. As such, the receivers require extensive signal 25 processing capabilities in order to effect the task of detecting the data in the presence of the unwanted signals. This represents a task of some considerable complexity. As such, it may not be possible to detect the data in real time, because state of the art signal processors are not able to execute the number of calculations required for the signal processing algorithms before the data must be presented at an output. However, it is not always necessary to solve signal processing problems exactly. It is known to be possible to only compute an approximation to the exact solution 30 without degrading the overall performance of the system. Computing an approximation to the solution reduces the amount of time spent solving the problem, reduces the amount of hardware required for implementing the algorithm, reduces the power consumption of the device and in some cases makes it possible to achieve real-time behaviour in the first place.

35 [0004] A part of a process most appropriate for detecting data communicated in accordance with a code division multiple access system requires the factorisation or decomposition of a correlation matrix. In order to effect real-time operation with known signal processors, it is necessary to provide an approximation to an exact solution of a factorisation of this correlation matrix. In an article entitled "Real-time feasibility of joint detection CDMA" by J. Mayer, J. Schlee and T. Weber, published in the proceedings of the second European Personal Mobile Communications Conference, Bonn, Germany, September 1997, pages 245 to 252, an approximation of a matrix factorisation is described 40 using a known numerical approximation process. However, the computational effort needed to perform this multi-user detection is still considerable.

45 [0005] A technical problem therefore exists in further reducing the computational complexity, or correspondingly increasing the accuracy which can be achieved using an approximation method to generate factor of a matrix.

[0006] The technical problem is addressed generally by considering the generation of the matrix factor by analysing 50 the structure matrix factor and determining from the structure which of the elements of the matrix must be calculated exactly using a factorisation algorithm, and which of the elements may be copied from the components calculated exactly.

55 [0007] According to the present invention there is provided a receiver which operate to detect radio signals and to recover data representative of the radio signals in the presence of interfering signals, said radio communications receiver comprising means to detect said radio signals and to generate digital base-band signals representative of the radio signals, means to form a correlation matrix from the base-band signals, and a data processor which operates to generate a factor of the correlation matrix and to recover the data from the factor, wherein the data processor operates to generate the factor by calculating first elements of the factor from the correlation matrix using a factorisation algorithm in accordance with a pre-determined structure of the factor matrix and forming second elements of the matrix by selectively copying said first elements from a first row in accordance with the pre-determined structure.

[0008] The pre-determined structure of the factor matrix may be determined in accordance with a band structure from the form of the calculation and the technique used to represent the data as radio signals.

[0009] The first and second elements may be rows or columns of the matrix. The term rows as used herein may be

substituted for the term column in that by inverting either the correlation matrix or the factor matrix or both, the columns become rows and the rows become columns. The factor may be an upper triangular matrix or a lower triangular matrix. The radio signals and the interfering signals may be generated in accordance with code division multiple access. The code division multiple access may be time division-code division multiple access.

[0010] The known approximation methods for factoring a correlation matrix as disclosed in the above mentioned reference entitled, "Real-time feasibility of joint detection CDMA", by Mayer, Schlee, Weber, have been guided by a mathematical view of the calculation and the treatment has been restricted to one specific algorithm for computing this part, namely the Cholesky algorithm. The present invention, however results from an algorithmic analysis of the matrix factorisation, from which a significant reduction in complexity is facilitated.

[0011] For the particular example of signal processing in a CDMA receiver, an approximation method greatly increases the capability of the receiver to cope with a technical problem known to those skilled in the art as the near/far problem, where different users are received with very different signal powers. As contemporaneously received unwanted signals with comparatively high signal powers tend to prevent the detection of wanted radio signals having a comparatively low signal power.

[0012] According to an aspect of the present invention there is provided a method of detecting a radio signal and recovering data representative of said radio signal in the presence of interfering signals, said method comprising the steps of:

- detecting said radio signals and generating digital base band signals representative of said radio signals,
- generating a correlation matrix (S) from said base band signals,
- generating a matrix factor (R) of said correlation matrix, and
- recovering said data from said factor (R), wherein said factor (R) is generated in accordance with the following operations;
- calculating first elements of the factor (R) from the correlation matrix (S) using a factorisation algorithm, in accordance with a pre-determined structure of the factor (R); and
- forming second elements of the matrix (R) by selectively copying elements from said first rows in accordance with said pre-determined structure.

[0013] According to a further aspect of the present invention, there is provided a method of generating at least one factor (R) of a matrix (S), said factor (R) being upper or lower triangular in form, said method comprising the steps of;

- calculating first elements of the factor (R) from the matrix (S) using a factorisation algorithm, in accordance with a pre-determined structure; and
- forming second elements of the matrix (R) by selectively copying elements from said first elements in accordance with said pre-determined structure.

[0014] One embodiment of the present invention will now be described by way of example only with reference to the accompanying drawings wherein;

40 FIGURE 1 is a schematic block diagram of a mobile radio telecommunications system;

FIGURE 2 is a schematic block diagram of a receiver which operates within the mobile radio communication system shown in Figure 1;

45 FIGURE 3 is an illustrative representation of a known method of generating an approximation of a factor matrix R , from a correlation matrix S ;

FIGURE 4 is a representation of a process of generating a factor matrix R , from a correlation matrix S according to the present invention; and

50 FIGURE 5 is a further illustration of a process generating a factor matrix of a correlation matrix S according to the present invention.

[0015] One embodiment of the present invention will now be described with reference to a mobile radio communications system which operates in accordance with code division multiple access. The present invention may operate with time division-code division multiple access (TD-CDMA) or wide band code division multiple access (W-CDMA). Both multiple access techniques will benefit from exploiting opportunities for approximation. The TD-CDMA system is required to perform joint detection of all users that are active in one time/frequency slot. Compared to a TD-CDMA

system, the number of simultaneously active users in a W-CDMA system is much higher. Therefore, it is currently not possible to jointly detect all users. However, it is possible to perform multi-user detection, where only a subset of all users is included in the joint detection problem and the rest is treated as interference. Approximation methods increase the number of users that can be included in one detection step and can thus increase the resistance of the system to the near/far effect. This in turn leads to reduced demands on the power control.

[0016] The illustrative embodiment of the present invention will be described with reference to a TD-CDMA system. An example of part of a mobile radio telephone system which operates in accordance with a TD-CDMA system is illustrated in Figure 1. In Figure 1, three base stations BS are shown to be interconnected via a mobile network infrastructure, NET. Data is communicated between mobile stations MS and the base stations BS, by transmitting and receiving radio signals 1, between the base and mobile stations operating within a radio coverage area effected by each of the base stations BS. The radio coverage area is shown illustrated as a broken line 2, and serves to indicate a boundary within which radio communications can be effected with the mobile stations MS. In the present illustrative embodiment the mobile stations MS communicate with the base stations BS in accordance with a TD-CDMA system. A more detailed explanation of how data is communicated using a time division CDMA system is provided in an article, entitled „Performance of a Cellular Hybrid C-TDMA Mobile Radio System Applying Joint Detection and Coherent Receiver Antenna Diversity“ by G. Blanz, A. Klein, M. Naßhan and A. Steil published in the IEEE Journal on Selected Areas in Communications, Volume 12, no. 4, May 1994 at page 568, the content of which is incorporated herein by reference. However for the present explanation it should be noted that communications using TD-CDMA systems is characterised in that radio frequency carrier signals via which communication of data is effected are divided into a plurality of time-slots. Each of these time-slots is assigned to a plurality of mobile stations which operate to communicate radio signals in the time-slot. In order to separate data communicated by the plurality of mobiles assigned to the same time-slot, each mobile is provided with a user specific code which is convolved with the data to be communicated. A receiver of the radio signals operates to separate data communicated by other mobile stations MS contemporaneously, in accordance with the user specific code. As will be appreciated, a similar arrangement is effected for data communicated from the base stations to the mobile stations.

[0017] A receiver which operates within the mobile radio communications system shown in Figure 1, is illustrated in Figure 2. In Figure 2 a wanted radio signal transmitted from a mobile station is represented by the line 1, whereas unwanted signals transmitted by other mobile stations are represented by the lines 4. The wanted and unwanted radio signals are detected by an antenna 6 and fed to a radio frequency down converter means 8 of the receiver 10. The radio frequency down converter means 8 operates to convert the received radio signals into a base band representation which are thereafter analogue to digital converted and fed to a first data processor 12. The first processor 12 operates to generate a correlation matrix S of the received radio signals in combination with a plurality of CDMA-spreading codes fed from a data store 14. The plurality of spreading codes held in data store 14 correspond to each of the spreading codes used to spread the data modulated onto the wanted and unwanted radio signals. The data store 14 may also include a set of training sequences which are embedded in the unwanted and wanted signals from which a channel impulse response of the communications channel through which the wanted and unwanted radio signals have passed may be estimated. The correlation matrix S , is thereafter passed to a further data processor 16 which operates to generate a factorised matrix R from the correlation matrix S from which data representative d of the wanted radio signals is generated an output on a conductor 18. Operation of the data processor will now be described in more detail.

[0018] The present example embodiment will be illustrated with regard to a receiver 10, which operates in accordance with TD-CDMA. As with W-CDMA, the problem can be reduced to solving a system of linear equations, after the correlation matrix S has been generated by the receiver. A received radio signal which has been generated in accordance with a TD-CDMA system can be modelled with an over-determined linear equation system, as illustrated in equation (1):

45

$$Ad = e \quad (1)$$

[0019] The system matrix A contains the combined channel impulse responses and spreading codes of each of the signals contemporaneously received in each time slot. The vector e contains the received antenna samples and the vector d denotes the unknown data symbols. This system of equations is solved according to a least squares criterion. This may be effected, by factoring a correlation matrix, formed from the matrix A , by multiplying the matrix with a Hermitian transpose of itself. This is illustrated by equation (2):

55

$$A^H Ad = A^H e \quad (2)$$

[0020] The data is recovered from equation (2), by forming a factor matrix R , as determined by equation (3):

$$A^H A = R^H R \quad (3)$$

5

[0021] Where in equation (3), R is upper triangular. From equations (2) and (3), equation (4) may be formed:

$$R^H R d = A^H e \quad (4)$$

10

[0022] Equation (4) can be trivially solved by two substitution operations to recover the data vector d . To facilitate the following explanation, the correlation matrix to be factored is designated S , where $S = R^H R$.

[0023] A key step in this process of recovering the data vector d , is generating the factor matrix R . This can be generated exactly using an algorithm known to those skilled in the art as the Cholesky algorithm, a description of which may be found in a publication entitled "Coding, Modulation and Multiuser Decoding for DS-CDMA Systems", PhD thesis by T-Ottosson, Chalmers University of Technology, Göteborg, Sweden, 1997. Having regard to the number of elements present in the matrix S , which is determined by the number of data symbols in the vector d , in combination with the length of the spreading sequence and the delay spread of the channel impulse response, the elements of the factor matrix R cannot be calculated exactly using the Cholesky algorithm, as this would either prevent real-time operation, or require a data processor with a processing power not currently available within the state of the art. However the matrix S is known to have a structure which is Hermitian, positive definite and is also a block Toeplitz matrix with a band structure. As such a known method for generating an approximation to the factor matrix R , is disclosed in the above referenced publication entitled "Realtime feasibility of joint detection CDMA" by Mayer, Schlee and Weber. This approximation will now be described with reference to Figure 3.

[0024] Figure 3 provides an illustrative representation of an approximation to the matrices S and R . For the correlation matrix S , and the matrix factor R , the following conventions are adopted:

$$S = (s_{ij}), S = A^H A$$

30

$R = (r_{ij})$, with R upper-triangular and $R^H R = S$, and for both S and R , $1 \leq i \leq n$, $1 \leq j \leq n$.

[0025] Let the blocks of S and R be of size $k \times k$. Then the block-Toeplitz structure of S and the approximate block-Toeplitz structure of R can be described as expressed in equation (5):

35

$$s_{ij} = s_{ik+jk} \text{ and } r_{ij} = r_{ik+jk} \quad (5)$$

[0026] Let \tilde{S} be a square sub-matrix from the upper left corner of S , which is shown in Figure 3, bounded by a dashed line 20. These elements of the matrix S , are bounded by an index \tilde{n} , as shown in Figure 3, and described mathematically by equation (6):

45

$$\tilde{S} = (s_{ij}), \quad 1 \leq i \leq \tilde{n} < n, \quad 1 \leq j \leq \tilde{n} < n \quad (6)$$

50

$$\tilde{R} = (r_{ij}), \quad 1 \leq i \leq \tilde{n} < n, \quad 1 \leq j \leq \tilde{n} < n \quad (7)$$

55

[0028] The exact matrix R can thus be approximated by computing the Cholesky factor from a smaller sub-matrix \tilde{S} of S and then filling the rest of R with copies of elements of \tilde{R} , as indicated by (5). As shown with the dashed line 20, 22, in Figure 3, \tilde{S} and \tilde{R} are placed at the upper left corner of S and R , respectively. After computing \tilde{R} , shown

as darker blocks on the right hand side of Figure 3, the remaining blocks of R , which are shown in a lighter shade, are copied from corresponding columns of the sub-matrix \tilde{R} , in accordance with a pre-determined mathematical structure.

[0029] As described in the above referenced publication "Real-time feasibility of joint detection CDMA", by Mayer, Schlee and Weber, the actual computation of \tilde{R} can be done with the Cholesky algorithm, which requires one square-root operation and one division for each computed row of \tilde{R} . Let v be the degree of the block-band structure of R , that is, that there are only $v \times k$ non-zero blocks directly on the diagonal and to the right of R in each block-row. To capture all the information of R , one needs to choose an \tilde{R} that has at least a size of $v \times v$ blocks, as indicated in Figure 3. This results in kv square root operations and kv divisions as required by the Cholesky algorithm.

[0030] This known technique for reducing a number of calculations required to generate the factor matrix R , is base on a mathematical assessment of the process for generating the matrix factor. However, the Applicant has observed that by analysing further the structure of the factor matrix R , it is possible to achieve further reductions in a number of calculations required to produce the factor matrix R . In this way, the approximate block-Toeplitz structure of R is exploited, to the effect that only a small part of \tilde{R} is computed, and then the remaining parts filled with suitable copies of the computed part. Exploiting this opportunity to reduce the number of calculations is an important part of being able to perform the joint-detection in real-time. The algorithms that can be used to compute \tilde{R} can be written in a form so that the elements of \tilde{R} are produced row-wise from top to bottom and within each row from left to right. While executing the algorithm, it is possible to leave out the computation of more of the elements r_{ij} , which are substituted with copies from those elements calculated exactly using the factoring algorithm, according to a pre-determined approximation for the structure of \tilde{R} . This approach leads to a close intertwining of the actual execution of the algorithm and the approximation process and thus results in great flexibility for controlling the approximation process.

[0031] This general principle can be applied to all algorithms that compute elements of a factor matrix R , using known factoring algorithms such as the Cholesky algorithm or other known algorithms such as the Block-Schur algorithm, which is known to those skilled in the art. Furthermore, it is beneficial for a wide range of signal processing tasks, like joint-detection in TD-CDMA systems and multi-user detection in W-CDMA systems.

[0032] The pre-determined structure, from which those elements of R , which need to be calculated using the factoring algorithm, and those elements which may be copied, can be substantially arbitrary and can vary dynamically in accordance with, for example, the prevailing conditions for data communications using a CDMA radio communications system.

[0033] There are many forms which the pre-determined structure may take. By carefully choosing one, it is possible to only compute the most "important" elements. Copying an element according to (5) makes only really sense when the copied-from element exists. This means that at least the first k rows of R should be computed, because there are no elements from which they could be copied from. As a result of the pre-determined structure, which may, as in accordance with the present embodiment, identify a band-structure of the correlation matrix S , only the first vk elements of each of k rows are non-zero. In mathematical terms, this can be expressed as shown in equation (8):

$$\text{shall we compute } r_{ij} ? = \text{is } i \leq k \text{ and } j \leq vk ? \quad (8)$$

[0034] Figure 4 provides an illustration of how the pre-determined structure of R , is used to determine which elements can be copied and which must be calculated using the factoring algorithm. As illustrated, the darker shaded blocks 24, of R , on the right hand side of Figure 4 are computed and the lighter blocks 26, are copied from them. Starting from this rule, the region of the computed elements can easily be enlarged. This generalisation has been achieved by examining the process of computing the Cholesky factor from an algorithmic point of view. The state of the art teaches the skilled person only a mathematical, high level analysis of the calculation of the matrix factor R . This mathematical view only provided knowledge of matrix-level computations. Analysing an implementation of the calculation, provides an insight into the structure of the factor matrix, from which a reduction in the number of computations can be effected. As will be clear to those skilled in the art, the illustrative embodiment of the present invention which finds an approximation to the generation of a Cholesky factor R , is one example of a general approach in which analysis of the structure of the factor matrix reveals a way in which a reduction in a number of computations can be achieved in calculating an approximation to a matrix factor.

[0035] Simulations have shown that exploiting these new opportunities for saving computational effort lead to an improvement over the existing solutions. These simulations have been carried out with a TD-CDMA model and have shown that the approximation to R according to the embodiment of the present invention, produces no reduction in the bit error rate of the recovered data, with a reduced amount of calculations. Only the first v blocks of the first block-row need to be computed, the rest of R can be copied from them. Compared to the known method of computing R , the embodiment reduces the amount of square root operations and divisions from vk to k . For typical channel models, this represents a reduction in the amount of calculations by around one third.

[0036] The new approach is applicable to a wide range of algorithms, such as the original Cholesky algorithm or the improved Block-Schur algorithm. It can be used in many signal processing tasks that require a matrix decomposition to reduce time and space complexity. For example, it can be used in the joint-detection process in a TD-CDMA system and for multi-user detection in W-CDMA systems. It not only provides a finer control over the amount and specific placement of elements which are calculated exactly, it also provides a means for interleaving computation and approximation. This enables the matrix factor calculation to be performed by doing a little computation, then a little bit of copying and then resuming the computation. This facilitates use of the general approximation approach for matrices with a different kind of structure. For example, when considering the problem of incorporating decision feedback into the joint detection process, the matrix S has a Toeplitz-block structure instead of block-Toeplitz structure. It is then beneficial to periodically alternate between computing and copying. There is no easy way to express this with matrix notation alone. Figure 5 provides an illustration of a different form of a Toeplitz-block structure with internal band structure and the layout of the elements of R according to whether they should be computed (dark) or copied (light).

[0037] As a further illustration of the example embodiment of the invention, a particular example of a calculation of a matrix factor R is provided in the following paragraphs, in comparison to a calculation using the Cholesky factoring algorithm.

[0038] The Cholesky algorithm for computing R can be expressed as follows:

```

20      for i in 1 to n
          for j in i to n
              compute  $r_{ij}$ 
            compute  $r_{ij}$ 
25       $x = s_{ij}$ 
          for k in 1 to i - 1
               $x = x - r_{ki}^* r_{kj}$ 
30      if  $j = i$ 
               $r_{ii} = \sqrt{x}$ 
35      else
               $r_{ij} = x / r_{ii}$ 
```

[0039] Note that the division in the case where $i \neq j$ can be replaced by a multiplication by pre-computing $1/r_{ii}$ once per row. The interleaving of actual computations and copy operations can then be achieved like this:

45

50

55

```

for i in 1 to n
  for j in i to n
    if we should compute  $r_{ij}$ 
      compute  $r_{ij}$ 
    else
      copy  $r_{ij}$ 
copy  $r_{ij}$ 
if i > k and j > k
 $r_{ij} = r_{i-k, j-k}$ 
else
 $r_{ij} = 0$ 

```

20

[0040] A numerical example of a correlation matrix S is provided as follows:

25

$$S = \begin{bmatrix} 4 & 2 & 0 \\ 2 & 4 & 2 \\ 0 & 2 & 4 \end{bmatrix}$$

30

[0041] In this example $k = 1$, that is, the matrix S is not really block-Toeplitz, but rather, it has an ordinary Toeplitz structure. The matrix S has a band structure with $v = 2$. The exact Cholesky factor R, to four decimal places is:

35

$$R = \begin{bmatrix} 2.0000 & 1.0000 & 0.0000 \\ 0.0000 & 1.7321 & 1.1547 \\ 0.0000 & 0.0000 & 1.6330 \end{bmatrix}$$

40

[0042] As can be seen, R also has band-structure with $v = 2$ and the elements down the diagonals can be considered to be approximately equal. This approximate equality is much more pronounced for larger matrices. Equation (8) provides for the case that only elements r_{11} and r_{12} should be computed, and the rest is copied. The approximating algorithm now starts by computing r_{11} , and then r_{12} . The element r_{13} should be "copied" and is set to zero because the element that would be approximately equal to it, r_{12} , does not exist. This is correct because r_{13} is known to be zero due to the band structure of R. The algorithm then proceeds to copy elements r_{22} , r_{23} and r_{33} from their respective approximations r_{11} , r_{12} and r_{22} . Thus, R according to equation (8) is:

50

$$R^{(8)} = \begin{bmatrix} 2.0000 & 1.0000 & 0.0000 \\ 0.0000 & 2.0000 & 1.0000 \\ 0.0000 & 0.0000 & 2.0000 \end{bmatrix}$$

55

[0043] The calculation of $R^{(8)}$ requires one square root operation and one division. Using the known approximation technique, we would have also had to calculate element r_{22} .

$$R^{(5)} = \begin{bmatrix} 2.0000 & 1.0000 & 0.0000 \\ 0.0000 & 1.7321 & 1.0000 \\ 0.0000 & 0.0000 & 1.7321 \end{bmatrix}$$

requiring two square root operations and two divisions.

[0044] Clearly, this is a better approximation than $R^{(8)}$. But considering that computing the rest of the second row does not involve the costly square root operation and division, it would be advantageous to also compute r_{23} (but not r_{33}). The matrix oriented approach known to those skilled in the art can not express this. The rule for this would be:

shall we compute r_{ij} ? \Rightarrow is $i \leq kI$ and $j \leq (v + I-1)k$? (9)

[0045] This rule computes all non-zero elements of the first kI rows. For our example, with $I = 2$ the factor matrix becomes;

$$R^{(9)} = \begin{bmatrix} 2.0000 & 1.0000 & 0.0000 \\ 0.0000 & 1.7321 & 1.1547 \\ 0.0000 & 0.0000 & 1.7321 \end{bmatrix}$$

with only two square roots and two divisions. This is a better approximation than $R^{(5)}$, with the same amount of square roots and divisions.

[0046] As will be appreciated by those skilled in the art various modifications may be made to the illustrative embodiment without departing from the scope of the present invention. In particular, multi-user detection in a W-CDMA system can be also effected. In this case data detection from wanted radio signals in the presence of unwanted radio signals is expressed according to equation (10):

$$\hat{b}_{dec} = dec(R_W^{-1} y) \quad (10)$$

[0047] In equation (10), where R_W is the cross-correlation matrix of the system (not a Cholesky factor), and $dec()$ is a function which determines a part of the complex plane within which the signals fall. The cross-correlation matrix R_W is a Hermitian, positive semi-definite, block-Toeplitz, band matrix. Solving equation (10) efficiently amounts again to computing the Cholesky factor of R_W . As a result of the special structure of R_W , as with the correlation matrix $A^H A$, the desired Cholesky factor R has the same band structure and is approximately block-Toeplitz.

Claims

1. A radio communications receiver which operates to detect radio signals and to recover data representative of the radio signals in the presence of contemporaneously detected interfering signals, said radio communications receiver comprising:
 - means to detect said radio signals (6, 8) and to generate digital base band signals representative of said radio signals,
 - means to form a correlation matrix (12) from said base band signals, and
 - a data processor (16) which operates to generate a factor (R) of said correlation matrix (S), and to recover said data (d) from said factor matrix (R), wherein said data processor (16) operates to generate said factor matrix (R) by:
 - calculating first elements of the factor (R) from the correlation matrix (S) using a factorisation algorithm, in accordance with a pre-determined structure of the factor matrix (R); and

- forming second elements of the matrix (R) by selectively copying first elements in accordance with said pre-determined structure.
2. A radio communications receiver as claimed in Claim 1, wherein said pre-determined structure of the factor (R), is determined in accordance with a band structure of the factor matrix (R).
3. A radio communications receiver as claimed in Claim 1 or 2, wherein the first elements are contained in at least one row of said factor (R), and said second elements are contained in at least one second row of said factor (R).
4. A radio communications receiver as claimed in any preceding Claim, wherein said first and second elements are present in the same row.
5. A radio communications receiver as claimed in Claim 4, wherein the data processor operates to generate said factor (R) in accordance with the following steps:
- for each row of said matrix factor (R) (for i in 1 to n);
 - determining, from the predetermined structure;
 - whether the elements of the row (for j in i to n) of the matrix (R) should be calculated using said factorisation algorithm, and calculating said element using said factorisation algorithm and corresponding elements from the correlation matrix (S); or
 - whether the elements of the row (for j in i to n) of the matrix (R) is one of the second elements and can be copied from said first elements, and copying said elements from said first elements.
6. A radio communications receiver as claimed in any preceding Claim, wherein the rows are columns of the factor (R) and the columns are the rows of the matrix (R).
7. A radio communications receiver as claimed in any preceding Claim, wherein the factor (R) is upper or lower triangular.
8. A radio communications receiver as claimed in any preceding Claim, wherein said radio signals and said interfering signals are generated in accordance with a code division multiple access scheme.
9. A radio communications receiver as claimed in any preceding Claim, wherein said factorisation algorithm is the Cholesky or Block-Schur algorithm.
10. A method of detecting a radio signal and recovering data representative of said radio signal in the presence of interfering signals, said method comprising the steps of;
- detecting said radio signals and generating digital base band signals representative of said radio signals,
 - generating a correlation matrix (S) from said base band signals,
 - generating a matrix factor (R) of said correlation matrix, and
 - recovering said data from said factor (R), wherein said factor (R) is generated in accordance with the following operations;
 - calculating first elements of the factor (R) from the correlation matrix (S) using a factorisation algorithm, in accordance with a pre-determined structure of the factor (R); and
 - forming second elements of the matrix (R) by selectively copying elements from said first rows in accordance with said pre-determined structure.
11. A method as claimed in Claim 10, wherein said pre-determined structure of the factor (R), is determined in accordance with a band structure of the factor matrix (R).
12. A method as claimed in Claim 10 or 11, wherein said first elements are contained in at least one first row of the factor (R), and said second elements are contained in at least one second row of the matrix factor (R).
13. A method as claimed in Claims 10, 11 or 12, wherein said first and second elements are present in the same row.
14. A method as claimed in Claim 13, wherein said factor (R) is generated in accordance with the following steps;

- for each row of said factor (R) (for i in 1 to n);
- determining, from the predetermined structure;
- whether the elements of the row (for j in i to n) of the matrix (R) should be calculated using said factorisation algorithm, and calculating said element using said factorisation algorithm and elements from the correlation matrix (S); or
- whether the elements of the row (for j in i to n) of the matrix (R) is one of said second elements and can be copied from said first elements, and copying said elements from said first elements.

5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95 100 105 110 115 120 125 130 135 140 145 150 155 160 165 170 175 180 185 190 195 200 205 210 215 220 225 230 235 240 245 250 255 260 265 270 275 280 285 290 295 300 305 310 315 320 325 330 335 340 345 350 355 360 365 370 375 380 385 390 395 400 405 410 415 420 425 430 435 440 445 450 455 460 465 470 475 480 485 490 495 500 505 510 515 520 525 530 535 540 545 550 555 560 565 570 575 580 585 590 595 600 605 610 615 620 625 630 635 640 645 650 655 660 665 670 675 680 685 690 695 700 705 710 715 720 725 730 735 740 745 750 755 760 765 770 775 780 785 790 795 800 805 810 815 820 825 830 835 840 845 850 855 860 865 870 875 880 885 890 895 900 905 910 915 920 925 930 935 940 945 950 955 960 965 970 975 980 985 990 995 1000 1005 1010 1015 1020 1025 1030 1035 1040 1045 1050 1055 1060 1065 1070 1075 1080 1085 1090 1095 1100 1105 1110 1115 1120 1125 1130 1135 1140 1145 1150 1155 1160 1165 1170 1175 1180 1185 1190 1195 1200 1205 1210 1215 1220 1225 1230 1235 1240 1245 1250 1255 1260 1265 1270 1275 1280 1285 1290 1295 1300 1305 1310 1315 1320 1325 1330 1335 1340 1345 1350 1355 1360 1365 1370 1375 1380 1385 1390 1395 1400 1405 1410 1415 1420 1425 1430 1435 1440 1445 1450 1455 1460 1465 1470 1475 1480 1485 1490 1495 1500 1505 1510 1515 1520 1525 1530 1535 1540 1545 1550 1555 1560 1565 1570 1575 1580 1585 1590 1595 1600 1605 1610 1615 1620 1625 1630 1635 1640 1645 1650 1655 1660 1665 1670 1675 1680 1685 1690 1695 1700 1705 1710 1715 1720 1725 1730 1735 1740 1745 1750 1755 1760 1765 1770 1775 1780 1785 1790 1795 1800 1805 1810 1815 1820 1825 1830 1835 1840 1845 1850 1855 1860 1865 1870 1875 1880 1885 1890 1895 1900 1905 1910 1915 1920 1925 1930 1935 1940 1945 1950 1955 1960 1965 1970 1975 1980 1985 1990 1995 2000 2005 2010 2015 2020 2025 2030 2035 2040 2045 2050 2055 2060 2065 2070 2075 2080 2085 2090 2095 2100 2105 2110 2115 2120 2125 2130 2135 2140 2145 2150 2155 2160 2165 2170 2175 2180 2185 2190 2195 2200 2205 2210 2215 2220 2225 2230 2235 2240 2245 2250 2255 2260 2265 2270 2275 2280 2285 2290 2295 2300 2305 2310 2315 2320 2325 2330 2335 2340 2345 2350 2355 2360 2365 2370 2375 2380 2385 2390 2395 2400 2405 2410 2415 2420 2425 2430 2435 2440 2445 2450 2455 2460 2465 2470 2475 2480 2485 2490 2495 2500 2505 2510 2515 2520 2525 2530 2535 2540 2545 2550 2555 2560 2565 2570 2575 2580 2585 2590 2595 2600 2605 2610 2615 2620 2625 2630 2635 2640 2645 2650 2655 2660 2665 2670 2675 2680 2685 2690 2695 2700 2705 2710 2715 2720 2725 2730 2735 2740 2745 2750 2755 2760 2765 2770 2775 2780 2785 2790 2795 2800 2805 2810 2815 2820 2825 2830 2835 2840 2845 2850 2855 2860 2865 2870 2875 2880 2885 2890 2895 2900 2905 2910 2915 2920 2925 2930 2935 2940 2945 2950 2955 2960 2965 2970 2975 2980 2985 2990 2995 3000 3005 3010 3015 3020 3025 3030 3035 3040 3045 3050 3055 3060 3065 3070 3075 3080 3085 3090 3095 3100 3105 3110 3115 3120 3125 3130 3135 3140 3145 3150 3155 3160 3165 3170 3175 3180 3185 3190 3195 3200 3205 3210 3215 3220 3225 3230 3235 3240 3245 3250 3255 3260 3265 3270 3275 3280 3285 3290 3295 3300 3305 3310 3315 3320 3325 3330 3335 3340 3345 3350 3355 3360 3365 3370 3375 3380 3385 3390 3395 3400 3405 3410 3415 3420 3425 3430 3435 3440 3445 3450 3455 3460 3465 3470 3475 3480 3485 3490 3495 3500 3505 3510 3515 3520 3525 3530 3535 3540 3545 3550 3555 3560 3565 3570 3575 3580 3585 3590 3595 3600 3605 3610 3615 3620 3625 3630 3635 3640 3645 3650 3655 3660 3665 3670 3675 3680 3685 3690 3695 3700 3705 3710 3715 3720 3725 3730 3735 3740 3745 3750 3755 3760 3765 3770 3775 3780 3785 3790 3795 3800 3805 3810 3815 3820 3825 3830 3835 3840 3845 3850 3855 3860 3865 3870 3875 3880 3885 3890 3895 3900 3905 3910 3915 3920 3925 3930 3935 3940 3945 3950 3955 3960 3965 3970 3975 3980 3985 3990 3995 4000 4005 4010 4015 4020 4025 4030 4035 4040 4045 4050 4055 4060 4065 4070 4075 4080 4085 4090 4095 4100 4105 4110 4115 4120 4125 4130 4135 4140 4145 4150 4155 4160 4165 4170 4175 4180 4185 4190 4195 4200 4205 4210 4215 4220 4225 4230 4235 4240 4245 4250 4255 4260 4265 4270 4275 4280 4285 4290 4295 4300 4305 4310 4315 4320 4325 4330 4335 4340 4345 4350 4355 4360 4365 4370 4375 4380 4385 4390 4395 4400 4405 4410 4415 4420 4425 4430 4435 4440 4445 4450 4455 4460 4465 4470 4475 4480 4485 4490 4495 4500 4505 4510 4515 4520 4525 4530 4535 4540 4545 4550 4555 4560 4565 4570 4575 4580 4585 4590 4595 4600 4605 4610 4615 4620 4625 4630 4635 4640 4645 4650 4655 4660 4665 4670 4675 4680 4685 4690 4695 4700 4705 4710 4715 4720 4725 4730 4735 4740 4745 4750 4755 4760 4765 4770 4775 4780 4785 4790 4795 4800 4805 4810 4815 4820 4825 4830 4835 4840 4845 4850 4855 4860 4865 4870 4875 4880 4885 4890 4895 4900 4905 4910 4915 4920 4925 4930 4935 4940 4945 4950 4955 4960 4965 4970 4975 4980 4985 4990 4995 5000 5005 5010 5015 5020 5025 5030 5035 5040 5045 5050 5055 5060 5065 5070 5075 5080 5085 5090 5095 5100 5105 5110 5115 5120 5125 5130 5135 5140 5145 5150 5155 5160 5165 5170 5175 5180 5185 5190 5195 5200 5205 5210 5215 5220 5225 5230 5235 5240 5245 5250 5255 5260 5265 5270 5275 5280 5285 5290 5295 5300 5305 5310 5315 5320 5325 5330 5335 5340 5345 5350 5355 5360 5365 5370 5375 5380 5385 5390 5395 5400 5405 5410 5415 5420 5425 5430 5435 5440 5445 5450 5455 5460 5465 5470 5475 5480 5485 5490 5495 5500 5505 5510 5515 5520 5525 5530 5535 5540 5545 5550 5555 5560 5565 5570 5575 5580 5585 5590 5595 5600 5605 5610 5615 5620 5625 5630 5635 5640 5645 5650 5655 5660 5665 5670 5675 5680 5685 5690 5695 5700 5705 5710 5715 5720 5725 5730 5735 5740 5745 5750 5755 5760 5765 5770 5775 5780 5785 5790 5795 5800 5805 5810 5815 5820 5825 5830 5835 5840 5845 5850 5855 5860 5865 5870 5875 5880 5885 5890 5895 5900 5905 5910 5915 5920 5925 5930 5935 5940 5945 5950 5955 5960 5965 5970 5975 5980 5985 5990 5995 6000 6005 6010 6015 6020 6025 6030 6035 6040 6045 6050 6055 6060 6065 6070 6075 6080 6085 6090 6095 6100 6105 6110 6115 6120 6125 6130 6135 6140 6145 6150 6155 6160 6165 6170 6175 6180 6185 6190 6195 6200 6205 6210 6215 6220 6225 6230 6235 6240 6245 6250 6255 6260 6265 6270 6275 6280 6285 6290 6295 6300 6305 6310 6315 6320 6325 6330 6335 6340 6345 6350 6355 6360 6365 6370 6375 6380 6385 6390 6395 6400 6405 6410 6415 6420 6425 6430 6435 6440 6445 6450 6455 6460 6465 6470 6475 6480 6485 6490 6495 6500 6505 6510 6515 6520 6525 6530 6535 6540 6545 6550 6555 6560 6565 6570 6575 6580 6585 6590 6595 6600 6605 6610 6615 6620 6625 6630 6635 6640 6645 6650 6655 6660 6665 6670 6675 6680 6685 6690 6695 6700 6705 6710 6715 6720 6725 6730 6735 6740 6745 6750 6755 6760 6765 6770 6775 6780 6785 6790 6795 6800 6805 6810 6815 6820 6825 6830 6835 6840 6845 6850 6855 6860 6865 6870 6875 6880 6885 6890 6895 6900 6905 6910 6915 6920 6925 6930 6935 6940 6945 6950 6955 6960 6965 6970 6975 6980 6985 6990 6995 7000 7005 7010 7015 7020 7025 7030 7035 7040 7045 7050 7055 7060 7065 7070 7075 7080 7085 7090 7095 7100 7105 7110 7115 7120 7125 7130 7135 7140 7145 7150 7155 7160 7165 7170 7175 7180 7185 7190 7195 7200 7205 7210 7215 7220 7225 7230 7235 7240 7245 7250 7255 7260 7265 7270 7275 7280 7285 7290 7295 7300 7305 7310 7315 7320 7325 7330 7335 7340 7345 7350 7355 7360 7365 7370 7375 7380 7385 7390 7395 7400 7405 7410 7415 7420 7425 7430 7435 7440 7445 7450 7455 7460 7465 7470 7475 7480 7485 7490 7495 7500 7505 7510 7515 7520 7525 7530 7535 7540 7545 7550 7555 7560 7565 7570 7575 7580 7585 7590 7595 7600 7605 7610 7615 7620 7625 7630 7635 7640 7645 7650 7655 7660 7665 7670 7675 7680 7685 7690 7695 7700 7705 7710 7715 7720 7725 7730 7735 7740 7745 7750 7755 7760 7765 7770 7775 7780 7785 7790 7795 7800 7805 7810 7815 7820 7825 7830 7835 7840 7845 7850 7855 7860 7865 7870 7875 7880 7885 7890 7895 7900 7905 7910 7915 7920 7925 7930 7935 7940 7945 7950 7955 7960 7965 7970 7975 7980 7985 7990 7995 8000 8005 8010 8015 8020 8025 8030 8035 8040 8045 8050 8055 8060 8065 8070 8075 8080 8085 8090 8095 8100 8105 8110 8115 8120 8125 8130 8135 8140 8145 8150 8155 8160 8165 8170 8175 8180 8185 8190 8195 8200 8205 8210 8215 8220 8225 8230 8235 8240 8245 8250 8255 8260 8265 8270 8275 8280 8285 8290 8295 8300 8305 8310 8315 8320 8325 8330 8335 8340 8345 8350 8355 8360 8365 8370 8375 8380 8385 8390 8395 8400 8405 8410 8415 8420 8425 8430 8435 8440 8445 8450 8455 8460 8465 8470 8475 8480 8485 8490 8495 8500 8505 8510 8515 8520 8525 8530 8535 8540 8545 8550 8555 8560 8565 8570 8575 8580 8585 8590 8595 8600 8605 8610 8615 8620 8625 8630 8635 8640 8645 8650 8655 8660 8665 8670 8675 8680 8685 8690 8695 8700 8705 8710 8715 8720 8725 8730 8735 8740 8745 8750 8755 8760 8765 8770 8775 8780 8785 8790 8795 8800 8805 8810 8815 8820 8825 8830 8835 8840 8845 8850 8855 8860 8865 8870 8875 8880 8885 8890 8895 8900 8905 8910 8915 8920 8925 8930 8935 8940 8945 8950 8955 8960 8965 8970 8975 8980 8985 8990 8995 9000 9005 9010 9015 9020 9025 9030 9035 9040 9045 9050 9055 9060 9065 9070 9075 9080 9085 9090 9095 9100 9105 9110 9115 9120 9125 9130 9135 9140 9145 9150 9155 9160 9165 9170 9175 9180 9185 9190 9195 9200 9205 9210 9215 9220 9225 9230 9235 9240 9245 9250 9255 9260 9265 9270 9275 9280 9285 9290 9295 9300 9305 9310 9315 9320 9325 9330 9335 9340 9345 9350 9355 9360 9365 9370 9375 9380 9385 9390 9395 9400 9405 9410 9415 9420 9425 9430 9435 9440 9445 9450 9455 9460 9465 9470 9475 9480 9485 9490 9495 9500 9505 9510 9515 9520 9525 9530 9535 9540 9545 9550 9555 9560 9565 9570 9575 9580 9585 9590 9595 9600 9605 9610 9615 9620 9625 9630 9635 9640 9645 9650 9655 9660 9665 9670 9675 9680 9685 9690 9695 9700 9705 9710 9715 9720 9725 9730 9735 9740 9745 9750 9755 9760 9765 9770 9775 9780 9785 9790 9795 9800 9805 9810 9815 9820 9825 9830 9835 9840 9845 9850 9855 9860 9865 9870 9875 9880 9885 9890 9895 9900 9905 9910 9915 9920 9925 9930 9935 9940 9945 9950 9955 9960 9965 9970 9975 9980 9985 9990 9995 9999

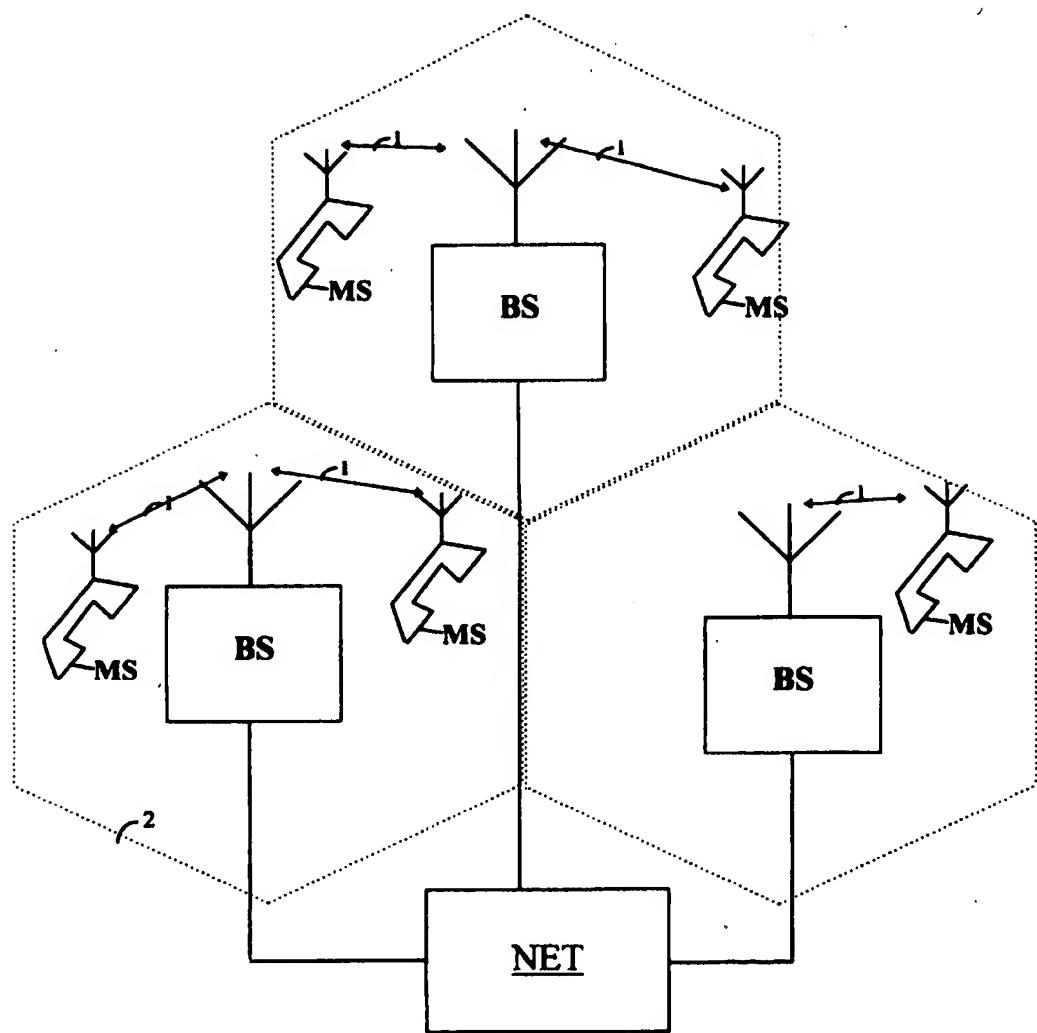


Fig. 1

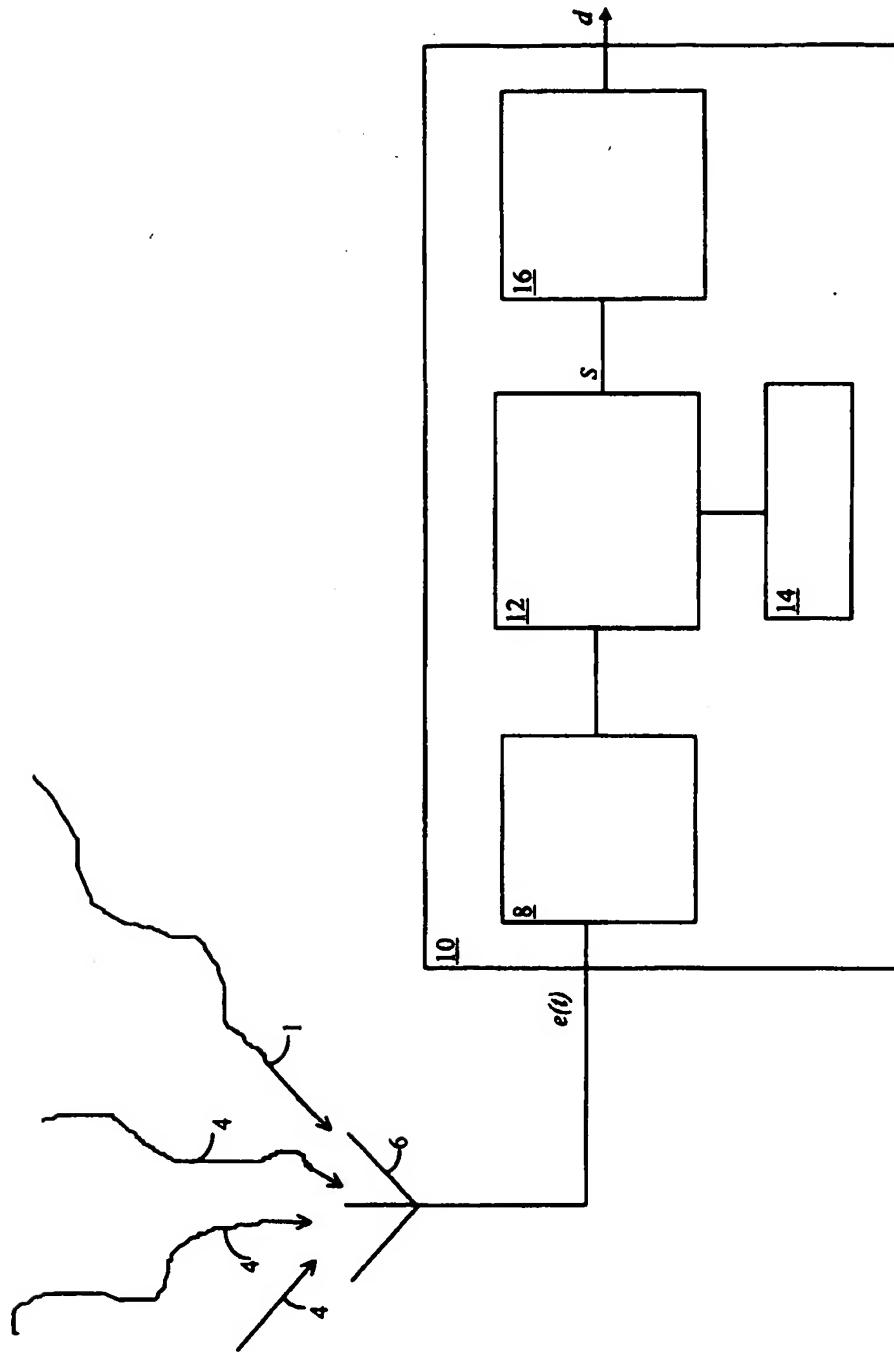


Fig. 2

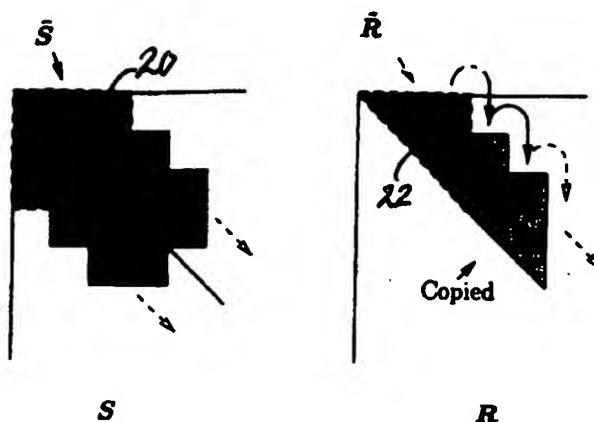


Figure 3

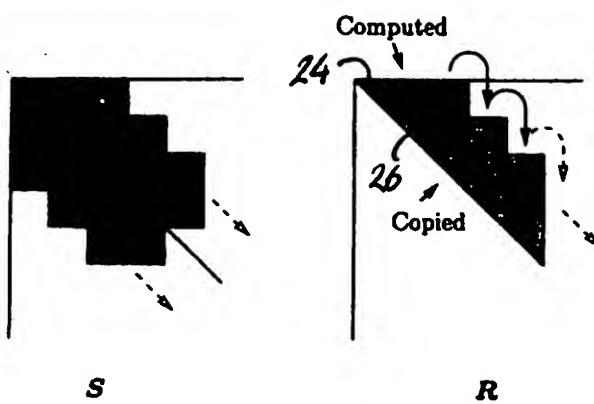


Figure 4

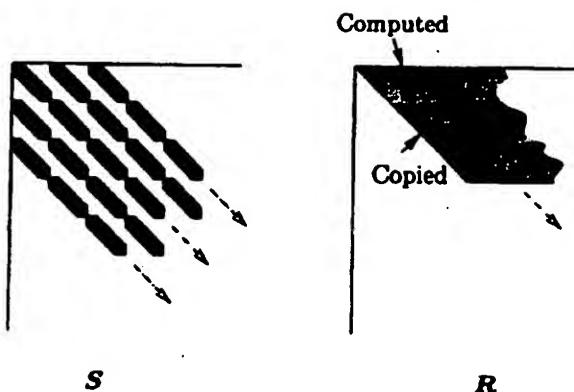


Figure 5



European Patent
Office

EUROPEAN SEARCH REPORT

Application Number
EP 98 11 2673

DOCUMENTS CONSIDERED TO BE RELEVANT			CLASSIFICATION OF THE APPLICATION (Int.Cl.)						
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim							
P, X	KARIMI H R ET AL: "A novel and efficient solution to block-based joint-detection using approximate Cholesky factorization" NINTH IEEE INTERNATIONAL SYMPOSIUM ON PERSONAL, INDOOR AND MOBILE RADIO COMMUNICATIONS (CAT. NO.98TH8361), PROCEEDINGS OF NINTH INTERNATIONAL SYMPOSIUM ON PERSONAL, INDOOR, AND MOBILE RADIO COMMUNICATIONS (PIMRC'98), BOSTON, MA, USA, 8-11 SEPT. 1998, pages 1340-1345 vol.3, XP002112134 1998, New York, NY, USA, IEEE, USA ISBN: 0-7803-4872-9 * abstract * * column 6, line 18 - column 8, line 27 *	1-26	H04B1/707						
D, X	MAYER J ET AL: "Realtime feasibility of joint detection COMA" EPMCC '97. SECOND EUROPEAN PERSONAL MOBILE COMMUNICATIONS CONFERENCE TOGETHER WITH 3. ITG-FACHTAGUNG, MOBILE KOMMUNIKATION, BONN, GERMANY, 30 SEPT.-2 OCT. 1997, no. 145, pages 245-252, XP002112135 ITG-Fachberichte, 1997, VDE-Verlag, Germany ISSN: 0341-0196 * page 247, column 2, line 3 - page 248, column 1, line 8 * * page 251, column 2, line 32 - page 252, column 1, line 24; figure 7 *	1-3, 7-11, 16-19, 24-26	TECHNICAL FIELDS SEARCHED (Int.Cl.) H04B						
<p>The present search report has been drawn up for all claims</p> <table border="1" style="width: 100%; border-collapse: collapse;"> <tr> <td style="width: 33%;">Place of search</td> <td style="width: 33%;">Date of completion of the search</td> <td style="width: 34%;">Examiner</td> </tr> <tr> <td>THE HAGUE</td> <td>13 August 1999</td> <td>Ó Donnabháin, E</td> </tr> </table> <p>CATEGORY OF CITED DOCUMENTS</p> <p>X : particularly relevant if taken alone Y : particularly relevant if combined with another document of the same category A : technological background O : non-written disclosure P : intermediate document</p> <p>T : theory or principle underlying the invention E : earlier patent document, but published on, or after the filing date D : document cited in the application L : document cited for other reasons R : member of the same patent family, corresponding document</p>				Place of search	Date of completion of the search	Examiner	THE HAGUE	13 August 1999	Ó Donnabháin, E
Place of search	Date of completion of the search	Examiner							
THE HAGUE	13 August 1999	Ó Donnabháin, E							